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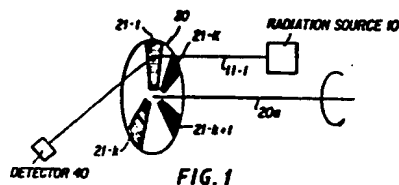
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(54) Plane linear grating for optically encoding information.

(57) An encoding disk including a multiplicity of linear gratings placed accurately on the disk to diffract a light beam to a fixed point in space accurately does so independently of the centering of the disk on its axis of rotation.



EP 0 096 476 A2

PLANE LINEAR GRATING FOR OPTICALLY
ENCODING INFORMATION

This invention relates to a rotatable structure containing linear diffraction gratings and in particular to the use of such a structure (such as a disk) to optically decode angular information in a mechanical system.

Rotatable holographic disks have been used for optical printers and for optically decoding the angular position of a rotating shaft in a mechanical system. However, they have not been used in a form where their centering is non-critical. Code disks to encode information wherein a number of annular bands possessing alternating opaque and transparent portions are circumferentially mounted at different radii along the disk are known in the art. In these disks, the lengths of the opaque regions dispersed with transparent regions along an annular band are used to determine the particular code to be transmitted by the disk. A light beam impinges the disk, the disk is rotated and the resulting interrupted pattern of light produces a desired code. These disks must be accurately centered and must remain centered to give high quality output signals. They are also subject to dust contamination and therefor must be kept clean.

This invention makes use of our discovery that a multiplicity of linear diffraction gratings placed

-2-

1 accurately on a disk (or a structure of any shape which
2 functions, like a disk) will diffract a light beam to a
3 fixed point in space independently of the centering of the
4 disk on the axis of rotation. This result is independent
5 of the number of gratings placed on the disk, the
6 orientation of the grating lines on the disk (with the
7 limitation that each grating must be oriented in a fixed
8 angular relationship to that angle of the mechanical shaft
9 on which the disk is located and which that particular
10 grating is to determine) and surprisingly even is inde-
11 pendent of the overlapping of different gratings.

12
13 Because one embodiment of the invention does not
14 require focused light on the disk, the sensitivity of the
15 system to dirt and dust is much less than that of a standard
16 encoder disk.

17
18 The invention will now be described, by way of example only, with
19 reference to the accompanying drawings, of which:

20 Figure 1 illustrates a system wherein light from a
21 radiation source is passed through a diffraction grating
22 onto a detector;

23
24 Figure 2 illustrates a system in accordance with this
25 invention wherein light from a radiation source is reflected
26 from a diffraction grating onto a detector;

27
28 Figures 3A and 3B illustrate the arrangements of
29 diffraction gratings on optical encoded disks in accordance
30 with this invention;

31
32 Figure 4 illustrates a system in which facet 21-k of
33 disk 20 (shown schematically only in Figure 4) diffracts a
34 light beam converged by lens 25 from parallel light beam
35 11-1 to form a focused beam having an angular convergence
36 θ on detector 40;

37
38

1 Figures 5A and 5B illustrate the gratings in two
2 facets at two different angles of orientation relative to
3 a reference line;
4

5 Figures 6A, 6B and 6C illustrate three different
6 grating configurations on disks;
7

8 Figures 7A and 7B illustrate, respectively, a disk
9 containing a plurality of gratings wherein certain of the
10 gratings are single, certain other of the gratings are
11 double and certain of the gratings are triple, and the
12 relative location of three detectors to detect the signals
13 produced by the grating of Figure 7A;
14

15 Figure 8 illustrates a prior art system wherein a
16 holographic disk is driven by a motor which also drives an
17 optical disk which makes and breaks a light beam from a
18 light source to a light detector thereby to produce pulses
19 for use in controlling the speed of the motor; and
20

21 Figure 9 illustrates a motor for driving a holographic
22 disk and the control circuit for controlling the speed of
23 the motor in accordance with the principles of this invention.
24
25
26

27 As shown in Figure 1, a radiation source 10 produces
28 a light beam 11-1 which is transmitted to a rotating disk
29 20. Disk 20 is of well-known design and is shown schemati-
30 cally for the purpose of simplicity. Formed on the surface
31 of disk 20 are diffraction gratings 21-1 through 21-K
32 where K is an integer representing the total number of
33 diffraction grating facets formed on the disk. Typically
34 K will depend upon the type of encoding to be incorporated
35 in the disk. For normal encoding, these gratings (also
36 called facets) are evenly spaced. However, these gratings
37 can also be logarithmically spaced or non-linearly spaced
38

-4-

1 in accordance with any desired rules.

2

3 Light beam 11-1 from radiation source 10 passes
4 through diffraction grating 21-1, for example, and then is
5 diffracted. The diffracted beam 11-2 then sweeps an arc
6 caused by the rotation of disk 20 about its axis 20a. A
7 portion of the arc is subtended by detector 40. Thus, the
8 light 11-1 from radiation source 10 is directed by dif-
9 fraction grating 21-1 and the directed beam 11-2 is picked
10 up by detector 40.

11

12 Figure 2 illustrates a similar structure wherein the
13 light beam 11-1 is reflected by diffraction grating 21-1
14 to form reflected beam 11-2. As in the situation where
15 diffraction grating 21-1 passes light beam 11-1, the re-
16 flected beam 11-2 is swept across detector 40 as the disk
17 20 is rotated about its axis 20a.

18

19 Figures 3A and 3B illustrate the structure of this
20 invention in greater detail. As shown in Figure 3A,
21 eight diffraction grating facets 21-1 through 21-8 are
22 formed on disk 20. Disk 20 has formed through its center
23 an opening 22 through which a rotational shaft is mounted.
24 We have discovered that the location of opening 22 is not
25 crucial to the successful operation of the encoding disk
26 of this invention and that the location of this opening
27 relative to the facets 21-1 through 21-8 has no effect
28 upon the output signal produced by detector 40 in the
29 structures of both Figure 1 and Figure 2. Thus, as shown
30 in Figure 3B, opening 22 can be precisely centered in disk
31 20 as shown with opening 22-0. Alternatively, opening 22
32 can be centered above the precise center of disk 20 as
33 shown by opening 22-1, to the left of this precise center
34 as shown by opening 22-2, below this precise center as
35 shown by opening 22-3 and to the right of this precise
36 center as shown by opening 22-4 or in fact anywhere else.
37 In all of these cases, the encoding disk 20 when rotated,

38

1 will produce a diffracted signal which strikes the detector
2 40 at precisely the correct time to produce an encoded
3 output signal completely independent of the location of
4 the opening 22 in the disk 20. Obviously, if the center
5 of rotation is placed at such a point where the facet does
6 not intercept the light beam (which would be the case for
7 some facets were the center to be placed at 22-5), no
8 light would be diffracted and therefor detector 40 would
9 not receive a signal. However, the facets that would
10 receive light would diffract accurately the encoded in-
11 formation. It should be apparent that a physical opening
12 in the disk need not be made and that locations 22-1 to
13 22-5 are merely locations of the center of rotation. The
14 disk could indeed be held by its edges or attached to a
15 shaft by some form of adhesive or even formed on the end
16 of a shaft.

17
18 In operation, as disk 20 rotates, the radiation 11-1
19 from source 10 is diffracted through an angle by the
20 grating 21-k where k is an integer given by $1 \leq k \leq K$. As the
21 disk 20 rotates, the plane of diffraction rotates. The
22 plane of diffraction is the plane defined by light beam
23 11-1 and diffracted beam 11-2. Since a linear grating is
24 used on disk 20 (i.e., each of gratings 21-k is linear),
25 the plane of diffraction is orthogonal to the direction of
26 the grating grooves and, we have discovered, is completely
27 independent of the centering of the disk containing the
28 grating. At an appropriate angle, the diffracted light
29 will intercept the detector 40 and produce an electrical
30 signal that will indicate the angular position of the
31 disk. For a multiplicity of K linear gratings, such as
32 shown in Figures 1, 2, and 3A, 3B, signals are produced by
33 detector 40 whose temporal spacing is determined solely by
34 the accuracy of the original placement of the gratings on
35 the encoded disk 20 and the angular velocity of the disk
36 in the mechanical system. Thus, the signals produced by
37 detectors 40 are independent of the centering of opening
38

1 22 in disk 20.

2

3 In the manufacture of disks 20, diffraction gratings
4 such as 21-1 through 21-K (Figure 1) can be produced by
5 the interference of two beams of mutually coherent light
6 by a process of interference and the diffraction grating
7 so produced is termed a holographic grating. Furthermore,
8 by the nature of holography, the diffraction grating so
9 produced can be superimposed to produce areas on a disk
10 such as disk 20 that will diffract multiple spots that can
11 be used to improve the numerical aperture of the diffracted
12 radiation in a system where a large number of gratings are
13 used. The numerical aperture NA of the diffracted radiation
14 is defined as $NA = N \sin \theta/2$ where N is the index of refraction
15 of the medium and θ is the angle as shown in Figure 4.
16 This multiple grating approach can also be used to produce
17 phase signals through the use of multiple detectors for
18 even higher resolution of the angular position of the
19 disk. In the schematic, parallel light beam 11-1 is
20 focused by lens 25 onto diffraction grating 21-k to form a
21 light beam 41-1 which converges onto detector 40 with
22 angle θ .

23

24 The operation of this system is not dependent upon
25 any particular angle of incidence of radiation 11-1 (Figure
26 1) nor on a particular angle of diffraction or on the
27 color or frequency of the radiation produced by radiation
28 source 10 (Figure 1). The diffraction grating lines of a
29 particular facet 21-k do not have to be parallel to a
30 radius of the disk. Rather, the facets can each be bound-
31 less extending over the total area of the disk. Moreover,
32 each facet can be superimposed upon other facets. When
33 the word "facet" is used in the specification, it is used
34 to refer to conveniently truncated borderless linear
35 diffraction gratings.

36

37 The spacing between the lines in the diffraction

38

1 grating in on embodiment of this invention used with a
2 photocopy machine was 1.27 microns. However, any spacing
3 desired can be used compatible with the purposes for which
4 the disk is to be used. The formation of a number of
5 superimposed diffraction gratings on the disk does not
6 degrade the output signals produced from the disk but
7 rather allows the disk to be used to produce a large
8 number of dots to cross a light detector during one rotation
9 of the disk.

10
11 The orientation of the detector relative to the
12 grating lines on the facets is illustrated in Figures 5A
13 and 5B. Thus, if the grating lines in a facet align
14 parallel with an arbitrary reference line as shown in
15 Figures 5A and 5B, the detectors should be oriented as
16 shown such that the diffracted light perpendicular to the
17 gratings strikes the detectors.

18
19 Figure 6A illustrates the location of grating facets
20 in different annular bands about a center of rotation of a
21 disk for the purpose of providing coded signals.

22
23 Figures 6B and 6C illustrate different facet con-
24 structions of use in this invention on a disk.

25
26 Figure 7A illustrates a composite disk containing a
27 selected family of facets utilizing single gratings, a
28 pair of opposed facets utilizing a double grating (i.e.
29 two gratings of different pitches superimposed on each
30 other) and two opposed facets with three sets of super-
31 imposed gratings on each facet. Figure 7B illustrates the
32 location of three detectors for detecting the light
33 diffracted by the triple gratings illustrated in Figure
34 7A.

35
36 It is also appropriate that the radiation can be
37 acoustic and that the detector will then be a microphone.
38

1 This technique also works with microwave radiation
2 and also systems where the wave nature of particles, such
3 as electrons, is utilized to diffract said particles.
4

5 In another embodiment, as an alternative to increasing
6 the number of facets, or in addition to increasing the
7 number of facets, the number of detectors can be increased
8 to provide greater accuracy of positional information.
9

10 While the disk 20 has been illustrated in the drawings
11 as circular, a non-circular substrate of material with
12 diffraction gratings formed thereon can be used in place
13 of a disk.
14

15 In one preferred embodiment of this invention, a
16 diffraction grating formed on a disk is used for two
17 purposes. First, the diffraction grating diffracts a
18 light beam which is then used to scan a photoconductive
19 drum and which is modulated in accordance with information
20 to be printed to produce, in a well-known manner, a replica
21 of the information in a line on the photoconductive drum.
22 Secondly, the diffraction grating is used to control a
23 servo controlled motor (typically a DC motor) to maintain
24 a constant angular velocity of the disk in the printing
25 system.
26

27 In the preferred embodiment, a holographic scanning
28 disk (such as disk 20 in Figure 2 with twelve facets each
29 subtending 30° arc and containing linear diffraction lines
30 perpendicular to the diffraction lines shown in facets 21
31 of Figure 2) for use in printing information on a photo-
32 conductive drum has allocated a portion of the facet at
33 the start of each scan for deflecting the laser beam (such
34 as beam 11-1) to a light detector (such as detector 40).
35 This light detector then sends a signal to a phase locked
36 loop which controls the speed of a motor (not shown in
37 Figure 2 but shown as motor 81 in Figure 9) in relation to
38

1 a reference frequency derived from a crystal oscillator.
2 By controlling the speed of the motor, a given number of
3 pulses per second are derived from the rotating holographic
4 disk. When the pulse generated by the light detector at
5 the start of each facet on the holographic disk is detected,
6 this also indicates the start of a print line on the
7 photoconductive drum. The beam (such as beam 11-1 in
8 Figure 2) diffracted by the facet is then converted in a
9 known manner, for example as disclosed in co-pending application Serial
10 No. 237,833 filed 25 February 1981 and assigned to us,

11 to form a straight
12 line along the surface of the photoconductive drum.
13 Application Serial No. 237,833 is hereby incorporated by
14 reference. The techniques for carrying out the phase-lock
15 loop control and for implementing the printing across the
16 photoconductive drum are well known in the art.
17

18 Figure 8 illustrates in schematic block diagram form
19 a motor control system of the prior art. In Figure 8,
20 motor 81 rotates holographic disk 85 in a manner well
21 known in the prior art to thereby diffract the light beam
22 88a from laser beam source 88 to produce a sweeping beam
23 88b. Beam 88b is then converted to a straight line using,
24 for example, the technique disclosed in patent application
25 Serial No. 06/238,383 filed February 25, 1981 and assigned
26 to us.

27 The
28 disclosure in application Serial No. 06/238,383 is hereby
29 incorporated by reference. Light beam 88b from laser beam
30 source 88 typically is swept along a line on a photoconductive
31 drum while its intensity is modulated thereby to store
32 information to be reproduced on a permanent medium in a
33 manner well known in the art.

34 To ensure the proper placement on the photoconductive
35 medium of the information to be stored, motor 81 must be
36 driven at an accurate speed. This is done by deriving a
37 sequence of pulses from the combination of optical disk
38

1 84, light source 82 and light detector 83. Optical disk
2 84 contains a series of transparent and opaque regions
3 uniformly placed around a selected annulus equidistant
4 from the center of rotation of disk 84. Light source 82
5 produces a continuous beam of light which is repetitively
6 interrupted by the opaque portions of the annular ring
7 formed on disk 84 as disk 84 rotates. Light detector 83
8 thus produces an output signal representing a sequence of
9 pulses the frequency of which is proportional to the speed
10 of motor 81. The pulse sequence from detector 83 is
11 compared to a sequence of pulses from oscillator 86
12 (oscillator 86 typically comprises a crystal oscillator)
13 in control circuit 87 and a difference signal is generated
14 from this comparison and is used to either speed up or
15 slow down motor 81 as appropriate.
16

17 One difficulty with the system of Figure 8 is that if
18 optical disk 84 is improperly centered on the axis of
19 rotation, the sequence of pulses produced by light detector
20 83 varies in frequency (i.e. the pulses speed up and slow
21 down in time) over one cycle of rotation of disk 84.
22 Thus, centering of disk 84 is extremely important to yield
23 accurate speed control.
24

25 In accordance with this invention, a control system
26 is provided which produces an output signal which is
27 independent of the centering of the holographic disk 85
28 (Figure 9) on the rotating shaft of motor 81. The light
29 beam 88a from laser beam source 88 periodically strikes
30 light detector 83 which is located to intercept light beam
31 88a at the start of each facet on holographic disk 85. A
32 typical holographic disk will contain 12 facets, each
33 subtending 30° of arc of the disk and each containing a
34 linear diffraction grating the grating lines of which in
35 one embodiment possess a pitch of 1.27 microns. Other
36 pitches can also be used. Thus, twelve times each cycle
37 of rotation of disk 85 beam 88b will strike light detector
38

1 83. The pulses produced by light detector 83 are trans-
2 mitted to control circuit 87 which compares the frequency
3 of the pulses from detector 83 to the frequency of the
4 output signal from crystal oscillator 86. Control circuit
5 87 then produces a control signal to ensure that motor 81
6 is driven at the proper speed in response to these signals.
7 Our discovery that the frequency of the output signal from
8 light detector 83 is independent of the centering of
9 holographic disk 85 on the axis of rotation 81a of motor
10 81 thus makes possible a substantial reduction in the cost
11 of manufacture of the holographic scanning system of the
12 type disclosed in the above-cited U.S. application Serial
13 No. 06/238,383. The accuracy of the time interval between
14 pulses from detector 83 depends upon the accuracy with
15 which the gratings are placed on disk 85. These gratings
16 can be placed very accurately on the disks using well
17 known techniques.

18
19 Prior art structures used a separate disk which had
20 to be accurately centered on the motor shaft to make and
21 break successive pulses of light from a light source to a
22 light detector and then compare the light pulses passed
23 by this disk to a known frequency. The system of our
24 invention thus eliminates one optical disk and one light
25 source compared to the prior art system, thus significantly
26 reducing component costs. But equally important, the fact
27 that the disk containing the linear diffraction grating
28 does not have to be accurately centered on the motor shaft
29 while still yielding pulses of uniform frequency from
30 detector 83 produces an additional significant saving.

31
32 In an embodiment where the mechanical system might
33 produce large differences in side forces on the shaft
34 holding the encoding disk as a function of position or
35 time, the disk and system of this invention would have its
36 accuracy unaffected by the eccentricity which might result from
37 these side forces.

38

1 The above disclosure is meant to be exemplary only,
2 not limiting. The scope of the invention is intended to
3 be definẽd solely by the attached claims.
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CLAIMS

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1. An encoding substrate comprising:

a substrate of material mounted so as to be capable of being rotated;

at least one linear diffraction grating formed in said material for the purpose of decoding angular position.

2. Structure as in Claim 1 including

means formed with said substrate for mounting said substrate on a shaft of rotation;

wherein said means formed with said substrate for mounting said substrate is not required to be precisely centered in said substrate.

3. Structure as in Claim 1 including a plurality of linear diffraction gratings formed equally spaced around the surface of said substrate where the axes of the grating lines so formed are angularly spaced equally around the substrate.

4. Structure as in Claim 1 including a plurality of linear gratings formed equally around the substrate where the axes of the grating lines are unequally spaced angularly but formed according to a prearranged code.

5. Structure as in Claim 3 wherein said linear diffraction gratings comprise transmission diffraction gratings suitable for transmitting incident light and producing a diffracted light beam.

1 6. Structure as in Claim 3 wherein said linear
2 diffraction gratings comprise reflective diffraction
3 gratings suitable for reflecting an incident light beam
4 and producing a diffracted reflected light beam.
5

6 7. Structure as in Claim 3 wherein said gratings
7 overlap such that multiple diffraction occurs at any one
8 angular position.
9

10 8. Structure as in Claim 1 including
11

12 means for rotating said substrate;
13

14 means for producing incident radiation on said
15 substrate; and
16

17 means for detecting radiation diffracted by said
18 substrate.
19

20 9. Structure as in Claim 8 wherein said means for
21 detecting produces an output signal representing the
22 information encoded in the diffraction gratings on said
23 substrate, and wherein the accuracy of said output signal
24 is independent of the center of rotation of said substrate.
25

26 10. Structure as in Claim 10 wherein said means for
27 detecting includes multiple detectors for producing in-
28 formation at a higher data rate.
29

30 11. Structure as in Claim 1 wherein different facet
31 arrangements are placed at different annular radii on the
32 substrate.
33

34 12. Structure as in Claim 1 wherein said light
35 interacting with said substrate is not focused to a small
36 spot on the grating but is large in relation to the diffraction
37 grating groove spacing and thereby immune to localized
38

1 grating defects.
2

3 13. Structure as in Claim 1 wherein the angle of
4 incidence from the normal on the substrate and the angle
5 of diffraction from the normal (when used in transmission)
6 are substantially the same which corresponds to the minimum
7 in diffraction angle and a point of angular insensitivity
8 for a transmission grating.
9

10 14. Structure as in Claim 1 wherein said substrate
11 comprises a disk.
12

13 15. Structure as in Claim 1 or 14 wherein said means
14 for mounting comprises an opening in said substrate suitable
15 for mounting said substrate on a shaft.
16

17 16. Structure which
18 comprises means for rotating a holographic disk
19 containing a selected number of facets of linear diffraction
20 gratings formed on the surface of said disk;
21

22 means for producing a monochromatic source of
23 light, said monochromatic source of light being arranged
24 such that said light is incident in sequence on said
25 linear diffraction gratings formed on said holographic
26 disks;
27

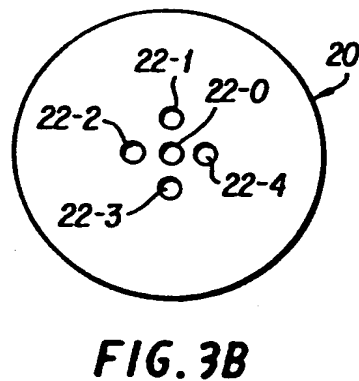
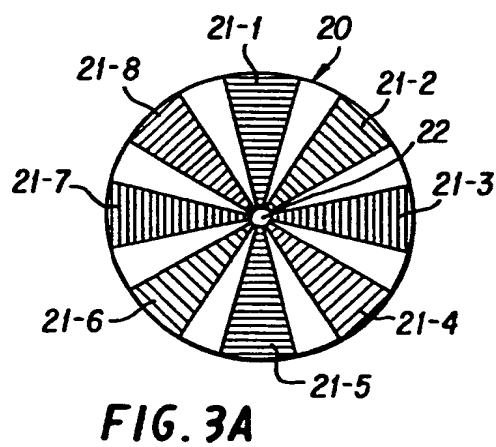
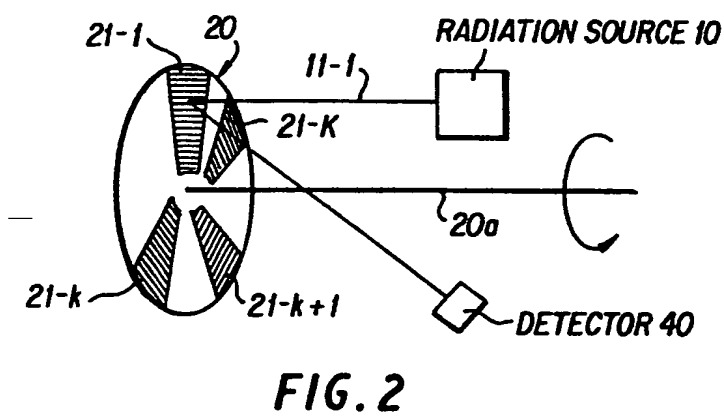
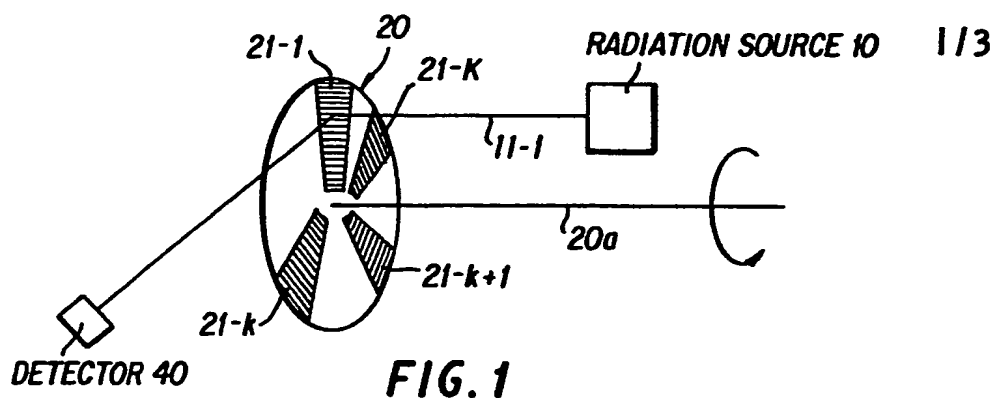
28 means for detecting the incidence of said monochromatic
29 light at the first portion of each facet of said linear
30 diffraction gratings and for producing an output signal
31 containing a plurality of pulses representative of each
32 said detection;
33

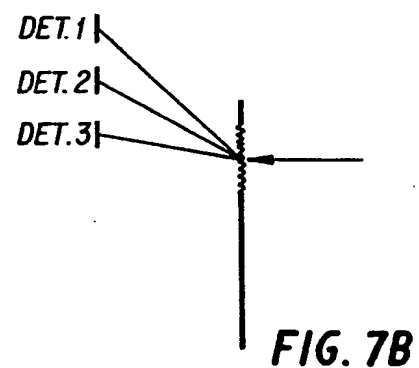
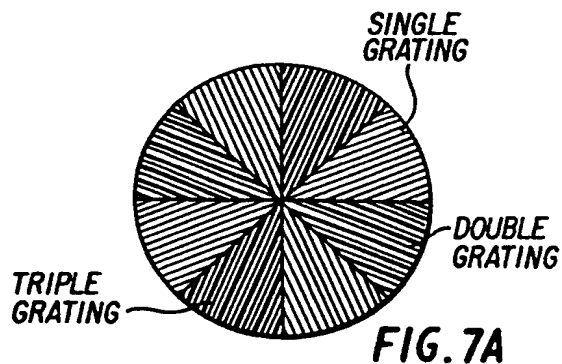
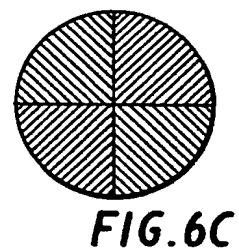
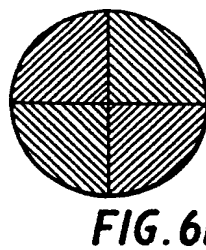
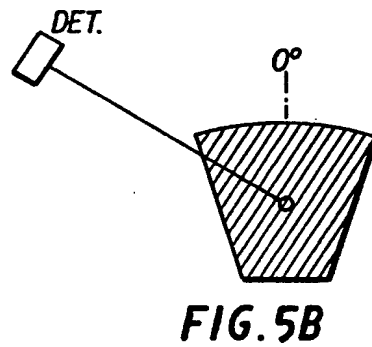
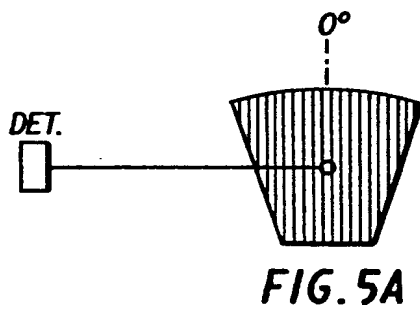
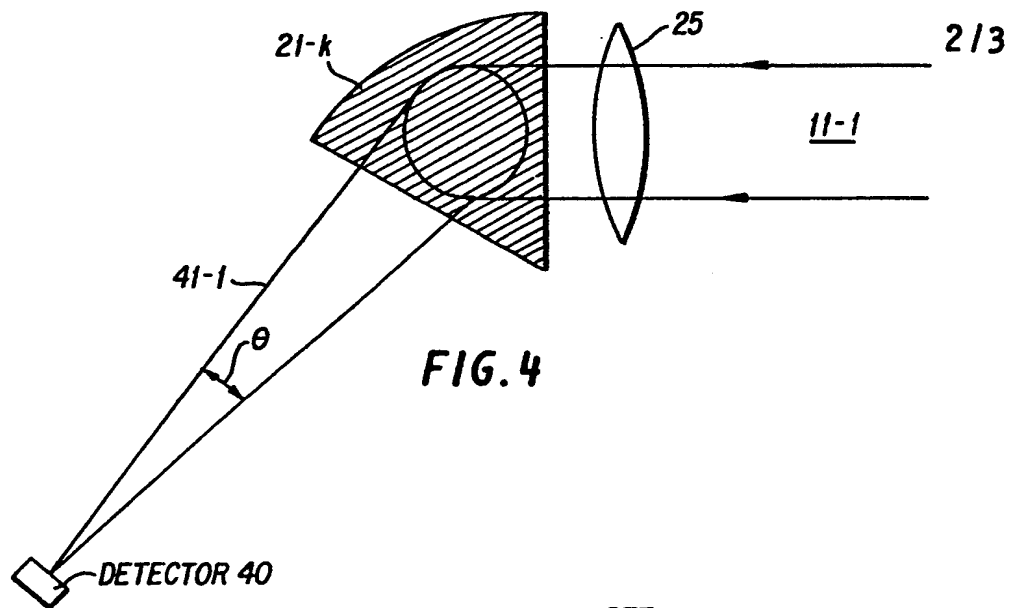
34 means for producing a reference frequency signal;
35 and
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37 means for comparing the frequencies of said
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1 output signals from said means for detecting and said
2 means for producing a reference frequency and for deriving
3 from said comparison a control signal to be used to control
4 the speed of said means for rotating said holographic
5 disk.
6

7 17. Structure as in Claim 16 wherein said means for
8 detecting the frequency of rotation of said holographic
9 disk is independent of the centering of said holographic
10 disk with respect to said means for rotating.
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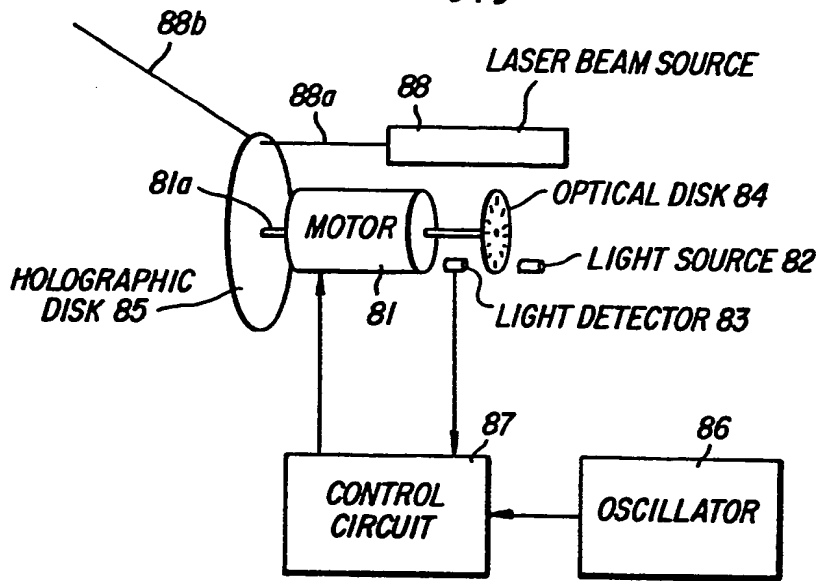


FIG. 8 PRIOR ART

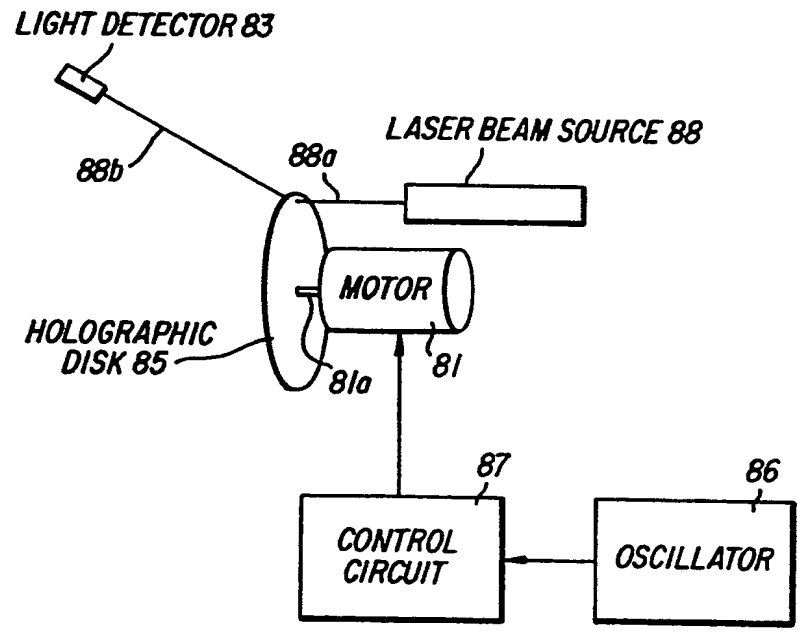


FIG. 9

12 **EUROPEAN PATENT APPLICATION**

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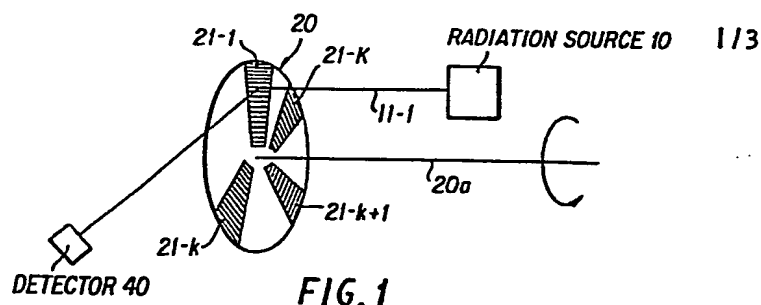
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54 **Plane linear grating for optically encoding information.**

57 An encoding disk including a multiplicity of linear gratings placed accurately on the disk to diffract a light beam to a

fixed point in space accurately does so independently of the centering of the disk on its axis of rotation.





European Patent
Office

EUROPEAN SEARCH REPORT

0096476

Application number

EP 83 30 2712

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. 3)
X	US-A-3 836 257 (CANON) * Column 14, line 16 - column 15, line 26; figures 5-7 *	1-6, 8, 9, 11, 14, 15	H 03 K 13/18 G 01 D 5/38 G 02 B 5/32
A	---	17	
A	US-A-3 862 428 (U.A.C.) * Column 3, lines 18-47; figures 1, 3 *	1, 8-12, 14-17	
A	--- LASER FOCUS, vol. 17, no. 6, June 1981, pages 70-82, Newton, Massachusetts, US; C.J. KRAMER: "Holographic laser scanners for nonimpact printing" * Column 3, line 10 - column 4, line 2; figure 2 * -----	1	
The present search report has been drawn up for all claims			TECHNICAL FIELDS SEARCHED (Int. Cl. 3) H 03 K 13/00 G 01 D 5/00 G 02 B 5/00
Place of search THE HAGUE		Date of completion of the search 12-11-1986	Examiner NUSSBAUMER C.P.
CATEGORY OF CITED DOCUMENTS			
X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			